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Effect of Thermal Neutrons on Fusion Power Measurement using the Micro-Fission Chamber in ITER

Masao Ishikawa, Takashi Kondoh, Takeo Nishitani, Yoshinori Kusama

Fusion Research and Development Directorate, Japan Atomic Energy Agency, Ibaraki, 311-0193, Japan

Abstract

A Micro-fission Chamber (MFC) provides time-resolved measurements of global neutron source strength and fusion power in ITER. The MFC is a pencil-sized gas counter containing the fissile material, ^{235}U. MFCs will be installed behind blanket modules at upper and lower outboard positions due to interface considerations with other equipment and the vacuum vessel. Measurements of the neutron source strength could be affected by cooling water in branch pipes, which will be installed near the MFC. The effect of the branch pipes upon the MFC is assessed by neutron transport calculation using MCNP 5. Results indicate a significant increase in the MFC response rate (up to ~ 40% higher) due to the branch pipe. The increase in the MFC response is caused by the slowing down of the neutrons due to the cooling water in the branch pipes. The effect of the thermal neutrons on the MFC response is especially significant. One possible solution to reduce the effect is to cover the MFC with a material that absorbs thermal neutrons such as cadmium. The ways in which the absorbent material may affect MFC response is analyzed through neutron transport calculation. Results indicate that the increase in the MFC response can be reduced to < 10 % through cadmium coating.

1. Introduction

The absolute measurement of neutron source strength is an important diagnostic in a burning plasma because fusion power may be derived directly from the neutron source strength. Micro-fission chambers (MFCs) [1], scheduled to be procured by the Japanese Domestic Agency for ITER, are one of the most important diagnostic tools for measuring total neutron source strength in ITER. The MFCs will be installed behind blanket modules in the upper and lower outboard regions of the vacuum vessel in ITER [2]. MFCs readings are very sensitive to the immediate environment. In previous work, the effect of streaming neutrons in the gap between blanket modules on the response of MFCs based on the installation location of the MFC, was analyzed [3, 4] through neutron transport calculation using MCNP version 5 [5]. However, the MCNP model for that calculation did not include in detail the effect of equipment that may be installed near the MFCs. Branch pipes (water cooling pipes) will be installed near the MFC. Since the cooling water flowing in the branch pipe slows down neutrons, the energy spectrum of neutrons which come into the MFC may be affected. This development may alter the detection efficiency of the MFC. In this work, the effect of the branch pipes is assessed by neutron transport calculation with MCNP in a detailed MCNP model in order to estimate the effect of this equipment upon the MFC.

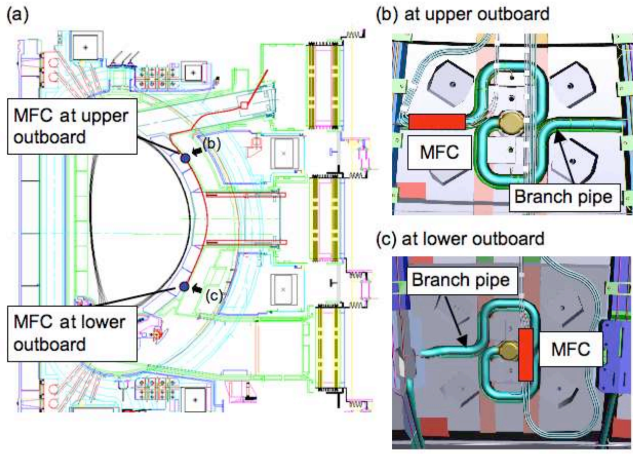

Fig.1 Location of MFCs on the ITER poloidal cross section (a) and schematic view of the installation position of MFCs at the upper outboard (b) and lower outboard (c) locations.

2. Micro-fission chamber

The MFC is a pencil-sized gas counter containing ^{235}U, which was developed as an in-core monitor for fission reactors [1]. In the MFC, a coating of UO_2 covers the outer cylindrical electrode. The active length is 76 mm, and the MFC contains a total amount of 10 mg of ^{235}U. The fusion power measurement range of MFCs extends from 100 kW – 1.5 GW by using both counting and Campbelling (mean square voltage) [6] modes with a temporal resolution of 1 ms. This measurement range meets ITER requirements for a neutron monitor [7].

MFCs will be installed behind blanket modules at both upper and lower outboard positions as shown in Fig.1 (a). The installation positions have been determined through neutron transport calculation with MCNP such that the average output of MFCs at the upper and lower outboard positions is insensitive to changes in the shape and position of the plasma [2]. At each proposed location, two MFCs and a dummy chamber with the same structure as an MFC but without any uranium coating on the electrode, will be installed. Two MFCs are installed at the same location so as to ensure that at least one remains operable over the course of ITER operations. The dummy chamber is also installed to compensate for the effect of gamma rays. In previous design work, the installation location of MFCs behind blanket modules was determined by taking into account the interface with other equipment and the vacuum vessel [4]. As shown in Fig.1 (b) and (c), the branch pipe will be installed just in front of the MFC. Since cooling water is flowing in the branch pipe, it may affect measurements of the MFC.

3. Effect of thermal neutrons on the MFC

The effect of the branch pipe on the MFC at the installation position is analyzed through neutron transport calculation with MCNP. A 20° toroidal section which includes the first wall, the blanket modules and the vacuum vessel are modeled in this calculation. Further, the branch pipe is modeled as shown in Fig.2. The neutron source is a toroidally symmetric source with energy of 14 MeV and the

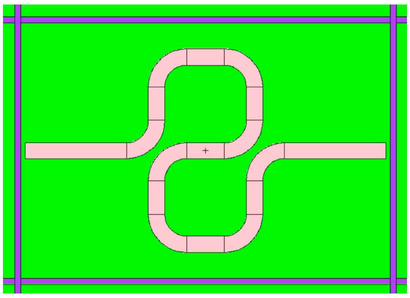

Fig.2 Image of the part of the branch pipe in the MCNP input file. Other shows the branch pipe and green shows the branket module.

neutron profile is compiled based on the main scenarios of ITER operations. In order to evaluate the effect of the cooling water, two models were developed for calculating the neutron spectra and responses behind the blanket module. In the first model, the branch pipe is filled with water. In the second model, the branch pipe is filled with materials of the blanket module (70% SUS + 30% water), which means that the blanket module does not include the branch pipe as shown in Fig.1 (b) and (c). A comparison of results of the two models indicates that neutron flux behind the branch pipe is hardly affected by the branch pipe. On the other hand, results indicate a significant increase in the MFC response rate (up to ~ 40% higher) due to the branch pipe. Findings reveal that neutrons are slowed down by the cooling water in the branch pipes. A cross-section of the fission reaction of ^{235}U becomes elevated due to the reduced energy of the neutrons as shown in Fig.3. As a result, the response rate of the MFC increases. Figure 4 shows the energy dependence of the neutron response at the position behind the branch pipe for the two models. Neutron response in the high energy range (> 0.1 MeV) is not affected by cooling water in the branch pipe, while that in the energy range of thermal neutrons (< 10^{-5} MeV) significantly increases. This indicates that the change in the energy spectrum of neutrons in the energy range of thermal neutron may strongly affect the response of the MFC, even though the total neutron source strength is not changed.

In order to reduce the effect of thermal neutrons on the response of the MFC, it is important to devise ways to deal with thermal neutrons. Covering the MFC with a material that absorbs thermal neutrons such as cadmium is one possible way to reduce their effect. Neutron transport calculations may help clarify the ways in which an absorbent material may affect

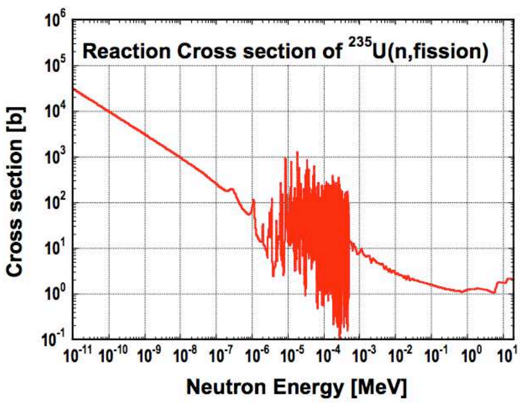

Fig.3 Energy dependence of a fission cross section of ^{235}U

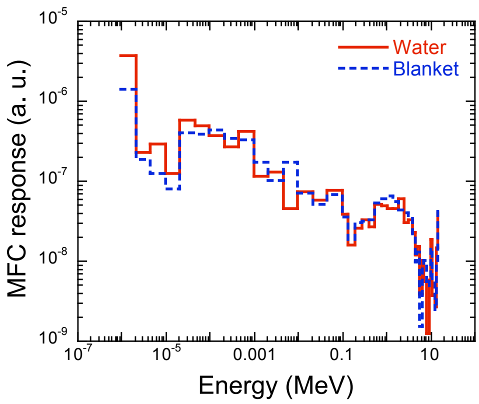

Fig.4 Energy dependence of MFC response to neutrons as they are affected by a branch pipe filled with (a) water or (b) materials used in the blanket modules.

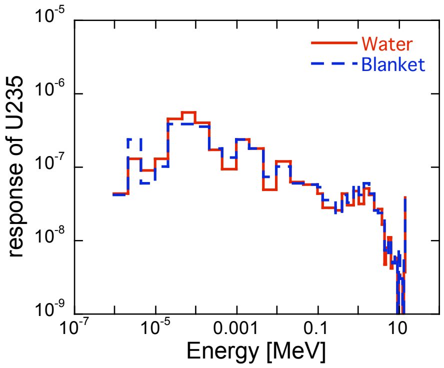

Fig.5 Energy dependence of the neutron response of a 1 mm cadmium-coated MFC in models in which a branch pipe is filled with (a) water or (b) materials used in the blanket module.

MFC response. The neutron source and the calculation methods are the same as for the previous calculation, except for a 1mm cadmium coating of the detector. Results are shown in Fig.5. Neutron response in both the high energy range and in the energy range of thermal neutrons is hardly affected by the cooling water in the branch pipe. An increase in the MFC response due to the slowing down of neutrons is reduced to < 10 %. Figure 5 shows that the energy dependence of the neutron response also becomes flatter. This suggests that the neutron response has become insensitive to changes in the energy spectrum of the neutrons due to their slowing down and scattering in the environment around the MFC.

4. Summary

The effect of the branch pipes upon the MFC is assessed through neutron transport calculations. As a result, the MFC response rate significantly increases (up to ~ 40%) due to the slowing down of neutrons due to the cooling water in the branch pipe. Thermal neutrons have a significant effect upon the MFC response. In order to reduce the effect of thermal neutrons, one possible solution is to cover the MFC with a material that absorbs thermal neutrons such as cadmium. The ways in which the absorbent material may affect MFC response is analyzed through neutron transport calculations. Results indicate that the increase in MFC response can be reduced to < 10 % with a cadmium coating. In future, it is investigated how thermal neutrons affect the MFC's measurement accuracy of neutron source strength.

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